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COMPUTER PROGRAM FOR ANALYSIS OF STRESS-STRAIN DATA, REVISED

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ABSTRACT

A computer program, previously developed for fitting analytic curves to experimental stress-strain data and described in AMMRC TR 76-12 and its Supplement, has been revised. The program determines the three parameters required for the Ramberg-Osgood equation and two additional constants for a power law approximation for data beyond the Ramberg-Osgood secant yield stress. The revisions include a routine to arrange the input data in increasing order of stress-strain magnitude; a new method for tangent modulus calculation; a data extrapolation routine for the case where the last input data point is a small increment below the secant yield stress; additional statistical calculations to indicate goodness-of-fit of the data; and output values expressed in S-I metric units as well as customary English units. A number of nonessential analyses and their associated outputs have been eliminated. User instructions, samples of the output, and a program listing are included.

CONTENTS

INTRODUCTION

This supplement describes a revised version of the computer program, now designated as ARPY 5, which was developed to analyze stress-strain data.* The revisions to AMMRC TR 76-12 are as follows.

1. Inclusion of a subroutine to arrange the input data in increasing order of stress-strain magnitude. (In the original version the program was aborted if the input data were not ordered.)

2. Inclusion of a data extrapolation routine for the case where the stress-strain values of the last data point are just below those of the S_1 yield values. (In the original version if the last data point was not equal to or larger than S_1, the Ramberg-Osgood secant yield stress, the calculations were aborted.)

3. Inclusion of a new method for tangent modulus calculations.

4. Inclusion of computations for the correlation coefficient.

5. Inclusion in the output of the stress-strain parameters expressed in S-I metric units.

6. Elimination of all plastic strain component analyses.

7. Miscellaneous revisions: Elimination of optional Table 2 (tangent modulus) and Table 3 (plastic strain parameters). Inclusion of S-I metric unit values in optional Table 1 (comparison of input data with computed stress values). Computations of the elastic-plastic values of Poisson's ratio have also been eliminated.

Appropriate changes in the output formats have been made to accommodate the various revisions. There have also been some small changes made in notation, internal computations, input, or output. A few revisions have been made in the input data requirements but these are limited to data required on the header card.

Descriptions of the revisions are given in this report. Samples of the printed output and listings of the revised main program and the subroutines are given in appendixes.

DATA ORDERING

The routines for obtaining the Ramberg-Osgood S_1 and m parameters require that the data be in increasing order of stress-strain magnitude. The program contains a test for data order. If one or more data cards are not in the required order, a subroutine, called ORDER, orders the data. The subroutine contains a provision for aborting the ordering process if the number of iterations exceeds the number of data points. When this occurs the calculations for the given data set are aborted and a diagnostic message appears in the printout.

*PAPIRNO, R. *Computer Analysis of Stress-Strain Data: Program Description and User Instructions.* Army Materials and Mechanics Research Center, AMMRC TR 76-12, April 1976.

DATA EXTRAPOLATION FOR RAMBERG-OSGOOD ANALYSES

In the original version of the program, the stress value of the last input data point S(N) must equal or exceed the secant yield strength S_1, or the Ramberg-Osgood and subsequent analyses are aborted. Let a test stress S(T) be defined by

$$S(T) = 0.7E/E(N) \tag{1}$$

where E(N) is the strain value associated with S(N). Now let a test increment be defined by

$$\Delta S = S(N) - S(T). \tag{2}$$

Data Test

If ΔS is negative or zero, the last data point will have a stress value equal to or greater than S_1. If ΔS is positive, the case shown in Figure 1, then S(N) will always be less than S_1. In the revised program an additional test is done if the latter situation occurs. The ratio S(T)/S(N) is calculated. If the value of the ratio is 0.95 or greater, an additional data point is extrapolated; if the ratio value is less than 0.95, the R-O calculations are aborted. The value 0.95 was chosen arbitrarily to be the criterion of a last data point which was close to the S_1 stress.

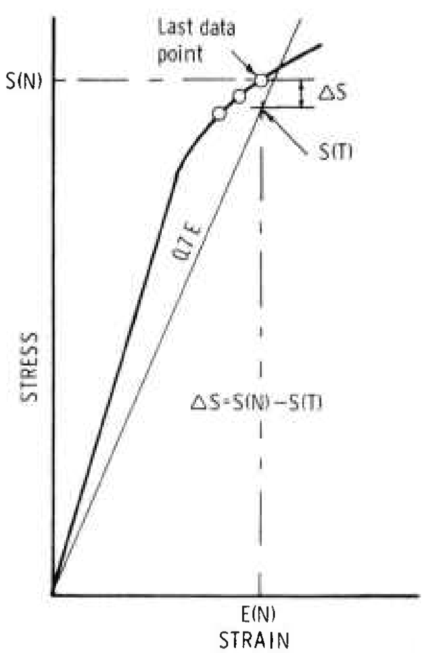

Figure 1. Identification of stress and strain values used in the program for a test with the extrapolation criterion.

Extrapolation Procedure

A curve of the strain-hardening type,

$$S = Ae^p, \tag{3}$$

is fitted to the last four data points of the set using a logarithmic least-squares procedure. The stress-strain coordinates of the intersection of this curve and the secant modulus line, 0.7E, are now calculated. This point is designated S_i, e_i in Figure 2. The strain difference between e_i and E(N), designated Δe in Figure 2, is determined.

Now $2\Delta e$ is added to E(N) for the extrapolated value of strain. The extrapolated value of stress is then calculated from Eq. 3, using the extrapolated value of strain. This procedure assures that the extrapolated data point will always be in excess of the secant yield stress.

The program now treats the extrapolated point as if it were the last data input point for R-O computations. However, a diagnostic message appears in the output printout advising the user that the extrapolation procedure has been employed. The message also contains the stress and strain values of the

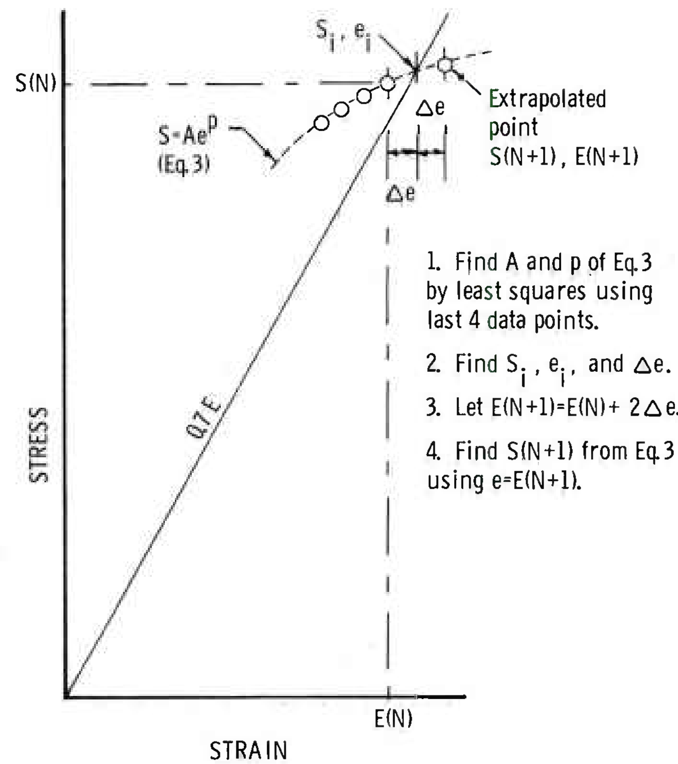

Figure 2. Extrapolation procedure outline.

extrapolated point. No entries are made for the extrapolated point in the optional output table; a message is printed to this effect at the end of the table.

TANGENT MODULUS

If the Ramberg-Osgood expression is differentiated, the resulting tangent modulus expression is given by

$$dS/de = E_t = E/[1 + (3m/7)(S/S_1)^{m-1}]. \tag{4}$$

The corresponding expression for the strain hardening relation is

$$dS/de = E_t = Ape^{p-1}. \tag{5}$$

Expressing Eq. 5 in terms of stress,

$$E_t = Ap\ (S_1/A)^q\ (S/S_1)^q \tag{6}$$

where $q = (p-1)/p$.

When the value of E_t for stresses up to S_1 is found from Eq. 4 and for stresses beyond S_1 from Eq. 6, there is likely to be a discontinuity at the S_1 stress value. This discontinuity can have two forms as shown in graphs in Figure 3. Such a discontinuity leads to ambiguous results in calculations involving the tangent modulus for stress values at S_1 (for example, in plastic buckling).

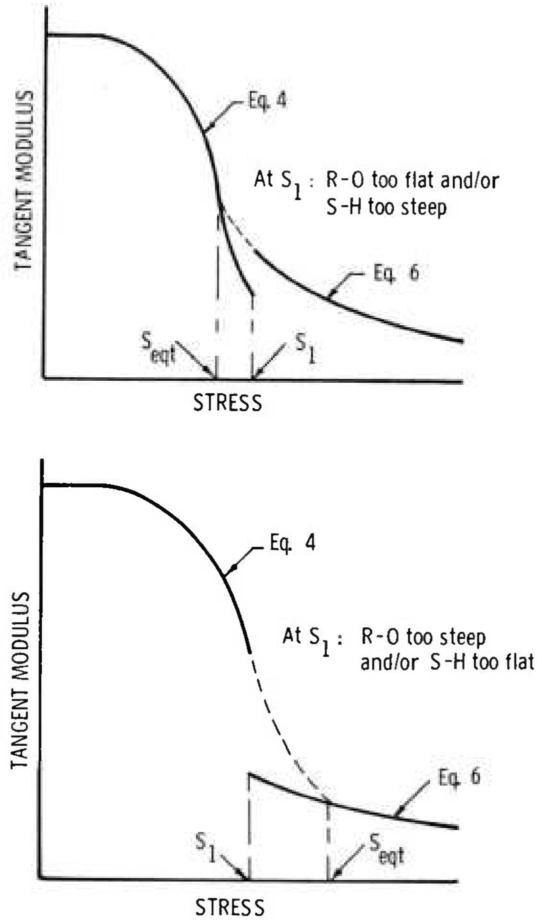

Figure 3. Two possible types of tangent modulus discontinuities at the secant yield stress (schematic).

Note, however, that it is possible for the two tangent modulus curves to intersect, thereby eliminating the discontinuity. The stress value at the intersection has here been designated as the equitan stress S_{eqt}. This stress value becomes one additional parameter to describe the stress-strain properties.

The equitan stress is found in the program by solving Eq. 4 and Eq. 6 simultaneously, using an iterative procedure. This is done by a subroutine called ISOTAN. At the equitan stress,

$$E/[1 + (3m/7)(S/S_1)^{m-1}] = Ap(S_1/A)^q(S/S_1)^q. \tag{7}$$

Rearranging Eq. 7 results in

$$(S/S_1)^q + (3m/7)(S/S_1)^{q+m-1} - E/[Ap(S_1/A)^q] = 0. \tag{8}$$

The S value in Eq. 8 is the desired equitan stress.

It is possible for there to be no real solution for Eq. 8 or for solutions which are not useful for computation. The program contains tests which identify these cases and diagnostic messages appear in the printout. The nonsolution and nonuseful solutions for which tests are done are as follows.

1. No solution can be found in 100 iterations.

2. The computations diverge, resulting in numbers too large for the computer. (A running size-check of key calculated quantities is made in a subroutine called SIZECK.)

3. The equation has an imaginary solution.

4. The solution stress value is larger than the stress of the last data point.

5. The solution stress value is less than the proportional limit.

Shown in Figure 4 are the results of a computation for a titanium alloy. In this case the equitan stress is less than the secant yield stress. The curve-fitting parameters for the stress-strain data are as follows:

$E = 15.2 \times 10^6$ psi (104.8 GPa)

$S_1 = 165.57$ ksi (1141 MPa)

$m = 25.07$

$p = 0.1683$

$A = 333.6$ ksi (2300 MPa)

The computed value of the equitan stress is 162.36 ksi (1119 MPa).

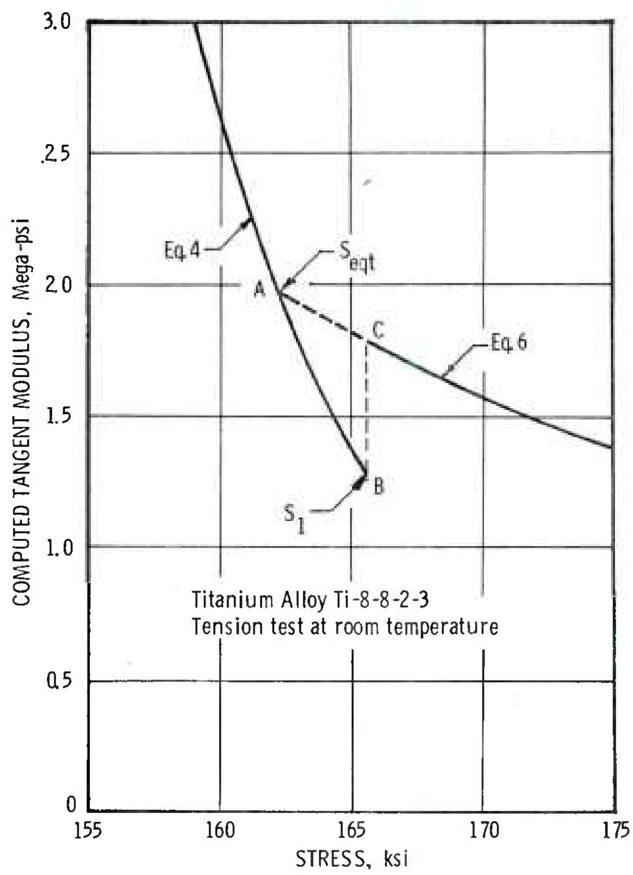

Figure 4. Computed tangent modulus values for a titanium alloy using analytical expressions derived from differentiating the Ramberg-Osgood and strain hardening equations.

Referring to Figure 4, note that there is a discontinuity in the tangent modulus if it is computed from Eq. 4 to S_1 and from Eq. 6 beyond S_1 at the values designated B and C in the figure. The discontinuity disappears when Eq. 4 is used for stress values to the equitan stress (A in the figure) and Eq. 6 thereafter. It should be noted, however, that the stress-strain values associated with the tangent modulus would be computed from the R-O curve to S_1 and from the S-H curve beyond S_1.

Applying the procedure results in a rough approximation of the tangent modulus and is suggested only for economy of storage of parameters. If a better approximation is required, then other more accurate methods should be used which operate directly on the stress-strain data. For the latter case the stress-strain data may also have to be stored.

MISCELLANEOUS REVISIONS

Metric Units

The output parameters are given in both Standard English units and S-I metric units. For the S-I units, the modulus of elasticity is given in GPa and all other stress values in MPa.

Header Card

An input Poisson's ratio is no longer required. The following changes from the information given in Table 1 of the Supplement to AMMRC TR 76-12 (page 4) are required

Columns 1-43	No change
Columns 44-50	Specimen Area, Format F7.4
Columns 51-62	Date of Test, Format 2A6
Columns 63-65	Output Option, Format I3; enter 1 in column 65 for optional table. Leave blank for standard output.

Optional Table

Calculations of point-for-point tangent modulus and elastic-plastic Poisson's ratio have been eliminated as well as calculations of plastic components of strain. These data were printed in optional Tables 2 and 3 of the original program and these have been eliminated. In the single optional table in the revised program, a point-by-point comparison is given of the actual input data stress values with those calculated from the approximate analytic expressions. The values are expressed in both Standard English units and S-I metric units.

Additional Parameters

The maximum strain of the data is printed out. Computations of the correlation coefficient are made for three separate data regions: elastic region; from the proportional limit to the secant yield stress; the strain hardening region. The values appear in the printout and serve, with the standard error of estimate, as an indicator of the goodness-of-fit of the analytic values to the test data.

APPENDIX A. SAMPLES OF OUTPUT

1. Sample of printed output of stress-strain parameters and statistical data for a specimen of ESR 4340 steel tested in tension.

2. Sample of tabular data for the same specimen in which the observed stress values are compared with those computed from the Ramberg-Osgood and strain-hardening analytic approximations. The columns labeled "Observed Strain" and "Observed Stress" are the input test data values.

ANALYTIC APPROXIMATION OF STRESS-STRAIN PROPERTIES
RAMBERG-OSGOOD AND STRAIN HARDENING PARAMETERS
OBTAINED FROM ANALYSES OF EXPERIMENTAL DATA

RAMBERG-OSGOOD EQUATION   EPS=SIG/E+(3/7)(S1/E)(SIG/S1)**M

STRAIN HARDENING LAW   SIG=A(EPS)**P

SPEC NO ESR101   4340 STEEL   TEMP= 20 C   STRAIN RATE= 1.0-05 PER SEC   TEST DATE 12-00-74   MAX STRAIN= .01930

***** STANDARD ENGLISH UNITS *****

MODULUS MEGA-PSI	S-INTCPT PSI	E-INTCPT MU-IN/IN	SPL KSI	S1 KSI	EXPNT M	.1-PCT SY KSI	.2-PCT SY KSI	COEFF-A KSI	EXPNT P	SEQT KSI
29.52	-94.	3.	162.20	174.92	103.90	173.35	174.52	.2181+03	.04623	174.06

***** S-I INTERNATIONAL METRIC UNITS *****

MODULUS GPA	S-INTCPT MPA	E-INTCPT MU-M/M	SPL MPA	S1 MPA	EXPNT M	.1-PCT SY MPA	.2-PCT SY MPA	COEFF-A MPA	EXPNT P	SEQT MPA
203.51	-.65	3.	1118.36	1206.01	103.90	1195.24	1203.24	.1504+04	.04623	1200.14

STANDARD ERROR OF ESTIMATE AND CORRELATION COEFFICIENT

STANDARD ENGLISH UNITS			S-I METRIC UNITS			CORR. COEFF.		
ELAST SEE KSI	R-O SEE KSI	S-H SEE KSI	ELAST SEE MPA	R-O SEE MPA	S-H SEE MPA	ELASTIC R	R-O R	S-H R
.755	.259	.395	5.21	1.78	2.72	.9999	.9929	.9802

COMPARISON OF COMPUTED STRESS VALUES WITH EXPERIMENTALLY OBSERVED VALUES
FOR SPECIMEN NO. ESR101   DATE OF TEST 12-00-74

		STANDARD ENGLISH UNITS			S-I METRIC UNITS		
OBSERVED STRAIN IN/IN	ADJUSTED STRAIN OR M/M	OBSERVED STRESS KSI	COMPUTED STRESS KSI	STRESS DEVIATION KSI	OBSERVED STRESS MPA	COMPUTED STRESS MPA	STRESS DEVIATION MPA
.000000	-.000003	.00	-.09	.094	.00	-.65	.65
.000354	.000351	10.54	10.35	.185	72.67	71.39	1.28
.000740	.000737	21.08	21.75	-.668	145.34	149.95	-4.60
.001066	.001063	31.61	31.37	.240	217.94	216.29	1.65
.001418	.001415	42.15	41.76	.390	290.61	287.92	2.69
.001768	.001765	52.69	52.09	.600	363.28	359.15	4.13
.002122	.002119	63.23	62.54	.691	435.96	431.19	4.76
.002593	.002590	73.77	76.44	-2.671	508.63	527.04	-18.42
.002848	.002845	84.30	83.97	.332	581.23	578.94	2.29
.003208	.003205	94.84	94.59	.246	653.90	652.20	1.70
.003572	.003569	105.33	105.34	.042	726.57	726.28	.29
.003927	.003924	115.92	115.82	.104	799.24	798.52	.72
.004281	.004278	126.46	126.26	.195	871.91	870.56	1.35
.004629	.004626	136.99	136.54	.454	944.51	941.38	3.13
.005006	.005003	147.53	147.66	-.134	1017.18	1018.11	-.92
.005362	.005359	158.07	158.17	-.102	1089.85	1090.55	-.70
.005801	.005798	168.61	168.01	-.403	1162.52	1165.30	-2.78
.006500	.006497	173.00	172.63	.367	1192.79	1190.26	2.53
.007000	.006997	173.50	173.54	-.040	1196.24	1196.52	-.28
.007500	.007497	174.00	174.14	-.138	1199.69	1200.64	-.95
.008100	.008097	174.73	174.66	.130	1205.13	1204.24	.90
.009000	.008997	175.10	175.41	-.310	1207.27	1209.41	-2.13
.011200	.011197	176.90	177.19	-.293	1219.68	1221.70	-2.02
.012860	.012857	177.95	178.33	-.379	1226.92	1229.53	-2.61
.014300	.014297	179.00	179.21	-.206	1234.16	1235.58	-1.42
.015000	.014997	180.06	179.60	.457	1241.47	1238.32	3.15
.019300	.019297	181.11	181.71	-.598	1248.71	1252.83	-4.12

APPENDIX B. PROGRAM LISTING

The program is written in FORTRAN IV and has been run on a UNIVAC 1106 computer. The listing includes the main program and five subroutines. The number of punch-cards for the program, including comment cards, is as follows:

Main program:	472 cards
Subroutine ORDER:	28 cards
Subroutine LSTSQ:	20 cards
Subroutine RJA75:	28 cards
Subroutine ISOTAN:	83 cards
Subroutine SIZECK:	13 cards
TOTAL:	644 cards

```
@FOR,IS MAIN
      COMMON S(100),E(100),EE(100),X(100),Y(100),CS(100),
     1SM(100),CSM(100),DVM(100),DV(100)
      DIMENSION ARRAY(1)
      EQUIVALENCE(S(1),ARRAY(1))
      SMC=6.894757
      READ 70,N1
      I1=0
1     I1=I1+1
      IF(I1.GT.N1)GO TO 999
      DO 2 I=1,1000
2     ARRAY(I)=0
C  READ IN OF DATA AND CONVERSION TO PSI AND IN/IN UNITS
      READ 71,SNO,XMTL,YMTL,TEMP,EDOT,N,N3,PPL,AREA,DATE3,DATE4,N2
      IF(N3.EQ.2)GO TO 4
      IF(N3.EQ.3)GO TO 6
C  RAW DATA IN KSI AND MICRO-IN/IN * N3=1 *
      DO 3 I=1,N
      READ 72,S(I),E(I)
      S(I)=S(I)*1000.
      E(I)=E(I)/(10.**6.)
3     EE(I)=E(I)
      GO TO 8
C  RAW DATA IN POUNDS LOAD AND IN/IN * N3=2 *
4     DO 5 I=1,N
      READ 73,S(I),E(I)
      S(I)=S(I)/AREA
5     EE(I)=E(I)
      GO TO 8
C  RAW DATA IN KSI AND IN/IN * N3=3 *
6     DO 7 I=1,N
      READ 74,S(I),E(I)
      S(I)=S(I)*1000.
7     EE(I)=E(I)
C  CHECK THAT DATA ARE ORDERED IN INCREASING STRESS/STRAIN MAGNITUDE
8     NOUT=0
      NL=N-1
      DO 9 I=1,NL
      IF(S(I).LE.S(I+1))GO TO 9
      IF(S(I).GT.S(I+1)) NOUT=NOUT+1
      IF(E(I).GT.E(I+1)) NOUT=NOUT+1
```

```
9       CONTINUE
        IF(NOUT.EQ.0)GO TO 10
C   ORDERING OF DATA
        MORDER=0
        CALL ORDER(N,S,E,EE,MORDER)
        IF(MORDER.EQ.0) GO TO 10
        EN=E(N)
        NEND=0
        GO TO 51
10      SPL=PPL*1000
        MX=0
        SEQT=0
        NRUN=0
11      NRUN=NRUN+1
C   ELASTIC DATA ANALYSIS
        I=0
12      I=I+1
        IF(S(I).GT.SPL)GO TO 13
        IF(I.EQ.N)GO TO 13
        GO TO 12
13      JPL=I
        J=JPL-1
        IF(J.GT.2)GO TO 14
        EN=E(N)
C   INSUFICIENT ELASTIC DATA
        NEND=1
        GO TO 51
14      DO 15 I=1,J
        X(I)=E(I)
15      Y(I)=S(I)
        LI=1
        LJ=J
        CALL LSTSQ(X,Y,SL,OF,LI,LJ)
        EMOD=SL
        IF(NRUN.EQ.2)GO TO 16
        S1OF=OF
        E1OF=-S1OF/EMOD
        PEOF=E1OF*(10.**6.)
        PSOF=S1OF
        EOFF=E1OF
        GO TO 17
16      S2OF=OF
        E2OF=-S2OF/EMOD
        EOFF=E2OF
        PSOF=S1OF+S2OF
        E12OF=E1OF+E2OF
        PEOF=E12OF*(10.**6.)
17      DO 18 I=1,N
```

```
18     E(I)=E(I)-EOFF
C   R-O ANALYSIS
       EN=E(N)
       SCT1=.7*EMOD
       SCT2=.85*EMOD
       CHK1=E(N)*SCT1
       IF(CHK1.GE.S(N))GO TO 19
       CHK3=CHK1/S(N)
       IF(CHK3.GE..95)GO TO 400
C   LAST DATA POINT STRESS VALUE LESS THAN S1
       NEND=2
       GO TO 33
C   EXTRAPOLATION ROUTINE
400    LI=N-3
       LJ=N
       MX=MX+1
       DO 401 I=LI,LJ
       X(I)=ALOG(E(I))
401    Y(I)=ALOG(S(I))
       CALL LSTSQ(X,Y,SL,OF,LI,LJ)
       XPNT=SL
       COEFF=EXP(OF)
       XTRPE=2.*(SCT1/COEFF)**(1./(XPNT-1.))-E(N)
       XTRPS=COEFF*XTRPE**XPNT
       N=N+1
       E(N)=XTRPE
       S(N)=XTRPS
19     I=J
20     I=I+1
       DEL2=SCT2*E(I)
       IF(DEL2-S(I))20,22,21
21     SL2=(S(I)-S(I-1))/(E(I)-E(I-1))
       B2=S(I)-SL2*E(I)
       S2=SCT2*B2/(SCT2-SL2)
       E2=S2/SCT2
       JS2=I-1
       GO TO 24
22     S2=S(I)
       E2=E(I)
       JS2=I
23     I=I+1
24     DEL1=SCT1*E(I)
       IF(DEL1-S(I))23,26,25
25     SL1=(S(I)-S(I-1))/(E(I)-E(I-1))
       B1=S(I)-SL1*E(I)
       S1=SCT1*B1/(SCT1-SL1)
       E1=S1/SCT1
       JS1=I-1
       GO TO 27
26     S1=S(I)
       E1=E(I)
       JS1=I
27     CHK2=JS1-JS2
       IF(CHK2.GE.2)GO TO 28
       NEND=3
C   INSUFFICIENT DATA IN KNEE REGION
       GO TO 33
```

```
28      JP=JS1+1
        XNUM=ALOG(7.*(EMOD*E2-S2)/(3.*S1))
        XDEN=ALOG(S2/S1)
        XM=XNUM/XDEN
        SPL=S1*(7.*EMOD/(3.*S1*(10.**6.)))**(1./XM)
        IF(NRUN.EQ.1)GO TO 11
        IF(MX.GT.0) ICHK=100.*E(N-1)/E1+.5
        IF(MX.GT.0) XTRPE=XTRPE+E12CF
        IF(MX.GT.0) EN=E(N-1)
        EPL=SPL/EMOD
        SY=S1*(7.*EMOD*.002/(3.*S1))**(1./XM)
        SY1=S1*(7.*EMOD*.001/(3.*S1))**(1./XM)
        DO 29 I=JPL,N
29      Y(I)=ALOG(S(I))
        NP=N-JP+1
        IF(NP.GE.3)GO TO 31
        DO 30 I=JP,N
        S(I)=0
        E(I)=0
        EE(I)=0
30      Y(I)=0
        N=JS1
C   INSUFFICENT S-H DATA
        NEND=4
        GO TO 33
C   STRAIN HARDENING ANALYSIS
C   COMPLETE DATA SET FOR NEND=5
31      NEND=5
        DO 32 I=JP,N
32      X(I)=ALOG(E(I))
        LI=JP
        LJ=N
        CALL LSTSQ(X,Y,SL,CF,LI,LJ)
        P=SL
        A=S1/(E1**P)
33      DT1=0
        DT2=0
        DT3=0
        SBAR1=0
        SBAR2=0
        SBAR3=0
        DR1=0
        DR2=0
        DR3=0
        COR1=0
        COR2=0
        COR3=0
        JRO=JS1-J
        JSH=N-JS1
        DO 34 I=1,J
        CS(I)=E(I)*EMOD
        DV(I)=S(I)-CS(I)
        DT1=DT1+DV(I)**2.
34      SBAR1=SBAR1+S(I)/J
        DO 35 I=1,J
```

```
35    DR1=DR1+(SBAR1-S(I))**2.
      DV1=SQRT(DT1/J)
      COR=1.-DT1/DR1
      IF(COR.LT.0) GO TO 36
      COR1=SQRT(COR)
36    IF(NEND.LT.4) GO TO 42
      DO 37 I=JPL,JS1
      Z=CS(I-1)/S1
      BB=E(I)*EMOD/S1
      CALL RJA75(Z,XM,BB)
      CS(I)=Z*S1
      DV(I)=S(I)-CS(I)
      DT2=DT2+DV(I)**2.
37    SBAR2=SBAR2+S(I)/JRO
      DO 38 I=JPL,JS1
38    DR2=DR2+(SBAR2-S(I))**2.
      DV2=SQRT(DT2/JRO)
      COR=1.-DT2/DR2
      IF(COR.LT.0) GO TO 39
      COR2=SQRT(COR)
39    IF(NEND.LT.5) GO TO 42
      DO 40 I=JP,N
      CS(I)=A*E(I)**P
      DV(I)=S(I)-CS(I)
      DT3=DT3+DV(I)**2.
40    SBAR3=SBAR3+S(I)/JSH
      DO 41 I=JP,N
41    DR3=DR3+(SBAR3-S(I))**2.
      DV3=SQRT(DT3/JSH)
      COR=1.-DT3/DR3
      IF(COR.LT.0) GO TO 43
      COR3=SQRT(COR)
      GO TO 43
C  EQUITAN STRESS COMPUTATION
C  NO R-O DATA OR NO S-H DATA * NO EQUITAN STRESS COMPUTATION
42    JTOUT=1
      GO TO 48
43    JTOUT=0
      SEQT=0.
      SEQTM=0.
      XMT=XM-1.
      XNT=(P-1.)/P
      CW=EMOD/(A*P*(S1/A)**XNT)
      KW=0
      W=1.
      CALL ISOTAN(W,XMT,XNT,CW,KW)
      IF(KW.LE.100) GO TO 46
      IF(KW.LE.200) GO TO 45
      IF(KW.LE.300) GO TO 44
C  NO SOLUTION CAN BE FOUND FOR ISOTAN EQUATION
      JTOUT=2
      GO TO 48
C  MAGNITUDE OF VARIABLES IN ISOTAN COMPUTATION TOO LARGE
44    JTOUT=3
      GO TO 48
C  IMAGINARY SOLUTION FOR ISOTAN EQUATION
45    JTOUT=4
      GO TO 48
```

```
46     SEQT=W*S1
       IF(SEQT.LE.SPL) GO TO 47
       IF(SEQT.LE.S1) GO TO 48
       EEQT=(SEQT/A)**(1./P)
       IF(EEQT.LT.EN) GO TO 48
C  EQUITAN STRESS  LARGER THAN STRESS OF LAST DATA POINT
       JTOUT =5
       SEQT=0
       GO TO 48
C  EQUITAN STRESS LESS THAN SPL
47     JTOUT=6
       SEQT=0
48     IF(N2.EQ.0) GO TO 50
       IF(NEND.LT.2) GO TO 51
       IF(NEND.LT.4) NPTS=J
       IF(NEND.EQ.4) NPTS=JS1
       IF(NEND.GT.4) NPTS=N
       DO 49 I=1,NPTS
       S(I)=S(I)/1000.
       SM(I)=S(I)*SMC
       CS(I)=CS(I)/1000.
       CSM(I)=CS(I)*SMC
       DV(I)=DV(I)/1000.
49     DVM(I)=DV(I)*SMC
50     EMOD=EMOD/(10.**6.)
       EMODM=EMOD*SMC
       PSOFM=PSOF*SMC/1000.
       DV1=DV1/1000.
       DV1M=DV1*SMC
       IF(NEND.LT.4) GO TO 51
       XTRPS=XTRPS/1000.
       XTRPSM=XTRPS*SMC
       S1=S1/1000.
       S1M=S1*SMC
       SPL=SPL/1000.
       SPLM=SPL*SMC
       SY=SY/1000.
       SYM=SY*SMC
       SY1=SY1/1000.
       SY1M=SY1*SMC
       DV2=DV2/1000.
       DV2M=DV2*SMC
       IF(NEND.LT.5) GO TO 51
       A=A/1000.
       AM=A*SMC
       DV3=DV3/1000.
       DV3M=DV3*SMC
       IF (JTOUT.GT.0) GO TO 51
       SEQT=SEQT/1000.
       SEQTM=SEQT*SMC
51     PRINT 100
       PRINT 101
       PRINT 102,SNO,XMTL,YMTL,TEMP,EDOT,DATE3,DATE4,EN
       IF(NEND.GT.1) GO TO 53
       IF(NEND.EQ.1) GO TO 52
       PRINT 103,SNO
       GO TO 1
```

```
52     PRINT 104
       GO TO 1
53     IF(NEND.EQ.4) GO TO 56
       IF(NEND.EQ.5) GO TO 57
       PRINT 105
       IF(NEND.EQ.2) GO TO 54
       PRINT 106
       GO TO 55
54     PRINT 107
55     PRINT 108
       PRINT 109,EMOD,EMODM,PSOF, PSOFM,PEOF,DV1,DV1M,COR1
       IF(N2.EQ.0) GO TO 1
       GO TO 59
56     PRINT 110
       IF(MX.GT.0) PRINT 111,ICHK,XTRPS,XTRPSM,XTRPE
       PRINT 112
       PRINT 113,EMOD,PSOF,PEOF,SPL,S1,XM,SY1,SY,DV1,DV2,COR1,COR2
       PRINT 114
       PRINT 115,EMODM,PSOFM,PEOF,SPLM,S1M,XM,SY1M,SYM,DV1M,DV2M,COR1,
      1COR2
       IF(N2.EQ.0) GO TO 1
       GO TO 59
57     IF(JTOUT.EQ.0) GO TO 58
       PRINT 116
       IF(JTOUT.EQ.2) PRINT 117
       IF(JTOUT.EQ.3) PRINT 118
       IF(JTOUT.EQ.4) PRINT 119
       IF(JTOUT.EQ.5) PRINT 120
       IF(JTOUT.EQ.6) PRINT 121
58     PRINT 122
       PRINT 123,EMOD,PSOF,PEOF,SPL,S1,XM,SY1,SY,A,P,SEQT
       PRINT 124
       PRINT 125,EMODM,PSOFM,PEOF,SPLM,S1M,XM,SY1M,SYM,AM,P,SEQTM
       PRINT 126
       PRINT 127,DV1,DV2,DV3,DV1M,DV2M,DV3M,COR1,COR2,COR3
       IF(N2.EQ.0) GO TO 1
59     PRINT 128,SNO,DATE3,DATE4
       DO 60 I=1,NPTS
60     PRINT 129,EE(I),E(I),S(I),CS(I),DV(I),SM(I),CSM(I),DVM(I)
       IF(MX.GT.0) PRINT 130
       IF(MX.GT.0) GO TO 1
       IF(NEND.EQ.4) PRINT 131
       IF(NEND.LT.4) PRINT 132
       GO TO 1
999    STOP
70     FORMAT(I3)
71     FORMAT(5A6,2I3,F7.2,F7.4,2A6,I3)
72     FORMAT(F7.2,F7.0)
73     FORMAT(F7.0,F7.5)
74     FORMAT(F7.2,F7.5)
100    FORMAT(1H1,T42,'ANALYTIC APPROXIMATION OF STRESS-STRAIN PROPERTIES
      1',/,   T45,'RAMBERG-OSGOOD AND STRAIN HARDENING PARAMETERS',/,T46,
      2'OBTAINED FROM ANALYSES OF EXPERIMENTAL DATA',/)
101    FORMAT(T35,'RAMBERG-OSGOOD EQUATION',6X,'EPS=SIG/E+(3/7)(S1/E)(SIG
      1/S1)**M',//,T36,'STRAIN HARDENING LAW',5X,'SIG=A(EPS)**P',/)
102    FORMAT(T10,'SPEC NO ',A6,2X,2A6,2X,'TEMP=',A6,' C',2X,'STRAIN RATE
      1= ',A6,' PER SEC',2X,'TEST DATE ',2A6,2X,'MAX STRAIN=',F7.5,/)
```

```
103   FORMAT(/,T25,3(5(1H*),6X),//,T32,'***** NO ANALYSIS WAS MADE OF TH
     1E DATA FOR SPEC.NO. ',A6,'*****',//,T25,'THE DATA CARDS COULD NOT
     2BE ARRANGED IN INCREASING ORDER OF STRESS MAGNITUDE.',//,T25,3(5(1
     3H*),6X))
104   FORMAT(/,T25,3(5(1H*),6X),//,T27,'***** INSUFFICIENT DATA IN THE E
     1LASTIC REGION WERE INPUT TO THE PROGRAM. *****',/,T24,'A VALID LEA
     2ST SQUARES ANALYSIS COULD NOT BE MADE AND THE CALCULATIONS WERE AB
     3ORTED.',//,T25,3(5(1H*),6X))
105   FORMAT(T10,'*****THERE WERE INSUFFICIENT DATA FOR A VALID R-O ANAL
     1YSIS')
106   FORMAT(1H+,T71,'TOO FEW DATA POINTS IN THE KNEE OF THE S-E CURVE.*
     1****',/)
107   FORMAT(1H+,T71,'STRESS VALUE OF LAST DATA POINT LESS THAN S1 STRES
     1S.*****',/)
108   FORMAT(T43,'***** ONLY ELASTIC DATA ANALYZED *****',//,T20,'ELASTI
     1C MODULUS',T42,'STRESS INTERCEPT',T62,'STRAIN INTERCEPT',T82,'STND
     2 ERROR OF ESTIMATE',T103,'CORREL',/,T20,'MEGA-PSI',T32,'GPA',T44,'
     3PSI',T54,'MPA',T64,'MICROSTRAIN',T87,'KSI',T97,'MPA',T103,'COEFF',
     4/)
109   FORMAT(T20,F7.2,T30,F7.2,T42,F7.0,T52,F7.2,T65,F7.0,T84,F7.3,T94,F
     17.2,T107,F6.4)
110   FORMAT(T14,'***** THERE WERE INSUFFICIENT INPUT DATA BEYOND THE S1
     1 STRESS FOR A VALID STRAIN HARDENING ANALYSIS.*****',/)
111   FORMAT(T14,'***** THE LAST INPUT DATA POINT HAD A STRAIN VALUE WHI
     1CH WAS', I3,' PERCENT OF E1.  AN ADDITIONAL POINT WAS',/,T14,'EXTR
     2APOLATED SO THAT AN R-O ANALYSIS COULD BE MADE. THE STRESS AND STR
     3AIN VALUES FOR THE EXTRAPOLATED DATA ARE',/,T14,F7.2,' KSI (',F8.2
     4,' MPA) AND',F8.6,' IN/IN (M/M).*****',/)
112   FORMAT(T50,'***** STANDARD ENGLISH UNITS *****',//,
     1T11,'MODULUS',T21,'S-INTCPT',T30,'E-INTCPT',T42,'SPL',T51,'S1',T59
     2,'EXPNT',T66,'.1-PCT SY',T77,'.2-PCT SY',T88,'ELAST SEE',T99,'R-O
     3SEE',T109,'ELAST',T118,'R-O',/,
     4T11,'MEGA-PSI',T24,'PSI',T30,'MU-IN/IN',T42,'KSI',T51,'KSI',T61,'M
     5',T69,'KSI',T80,'KSI',T91,'KSI',T101,'KSI',T111,'R',T119,'R',/)
113   FORMAT(T11,F7.2,T22,F7.0,T30,F7.0,T40,F7.2,T49,F7.2,T58,F7.2,T67,F
     17.2,T78,F7.2,T88,F7.3,T98,F7.3,T109,F6.4,T116,F6.4)
114   FORMAT(1H0,T46,'***** S-I INTERNATIONAL METRIC UNITS *****',//,
     1T11,'MODULUS',T21,'S-INTCPT',T30,'E-INTCPT',T42,'SPL',T51,'S1',T59
     2,'EXPNT',T66,'.1-PCT SY',T77,'.2-PCT SY',T88,'ELAST SEE',T99,'R-O
     3SEE',T109,'ELAST',T118,'R-O',/,
     4T13,'GPA',T24,'MPA',T31,'MU-M/M',T42,'MPA',T51,'MPA',T61,'M',T69,'
     5MPA',T80,'MPA',T91,'MPA',T101,'MPA',T111,'R',T119,'R',/)
115   FORMAT(T11,F7.2,T21,F7.2,T30,F7.0,T39,F8.2,T48,F8.2,T58,F7.2,T66,F
     18.2,T77,F8.2,T88,F7.2,T98,F7.2,T109,F6.4,T116,F6.4)
116   FORMAT(T10,'***** TO COMPUTE THE TANGENT MODULUS USE THE R-O CURVE
     1 TO S1 AND THE S-H CURVE BEYOND S1. AN EQUITAN STRESS COULD',/,T10
     2,'NOT BE DETERMINED BECAUSE')
117   FORMAT(1H+,T36,'NO SOLUTION COULD BE FOUND FOR THE ISOTAN EQUATION
     2.*****',/)
118   FORMAT(1H+,T36,'THE COMPUTATIONS INVOLVED NUMBER SIZES TOO LARGE F
     1OR THE COMPUTER.*****',/)
119   FORMAT(1H+,T36,'THE ISOTAN EQUATION HAD AN IMAGINARY SOLUTION.****
     1*',/)
120   FORMAT(1H+,T36,'THE VALUE FOUND WAS LARGER THAN THE MAX-STRESS DAT
     1A POINT.*****',/)
121   FORMAT(1H+,'THE VALUE FOUND WAS LESS THAN THE PROPORTIONAL LIMIT.*
     1****',/)
```

```
122     FORMAT(T50,'***** STANDARD ENGLISH UNITS *****',//,
       1T11,'MODULUS',T21,'S-INTCPT',T30,'E-INTCPT',T42,'SPL',T51,'S1',T59
       2,'EXPNT',T66,'.1-PCT SY',T77,'.2-PCT SY',T88,'COEFF-A',T100,'EXPNT
       3',T109,'SEQT',/,
       4T11,'MEGA-PSI',T24,'PSI',T30,'MU-IN/IN',T42,'KSI',T51,'KSI',T61,'M
       5',T69,'KSI',T80,'KSI',T90,'KSI',T102,'P',T110,'KSI',/)
123     FORMAT(T11,F7.2,T22,F7.0,T30,F7.0,T40,F7.2,T49,F7.2,T58,F7.2,T67,F
       17.2,T78,F7.2,T87,E9.4,T98,F7.5,T108,F7.2)
124     FORMAT(1H0,T46,'***** S-I INTERNATIONAL METRIC UNITS *****',//,
       1T11,'MODULUS',T21,'S-INTCPT',T30,'E-INTCPT',T42,'SPL',T51,'S1',T59
       2,'EXPNT',T66,'.1-PCT SY',T77,'.2-PCT SY',T88,'COEFF-A',T100,'EXPNT
       3',T109,'SEQT',/,
       4T13,'GPA',T24,'MPA',T31,'MU-M/M',T42,'MPA',T51,'MPA',T61,'M',T63,'
       5MPA',T80,'MPA',T90,'MPA',T102,'P',T110,'MPA',/)
125     FORMAT(T11,F7.2,T21,F7.2,T30,F7.0,T39,F8.2,T48,F8.2,T58,F7.2,T66,F
       18.2,T77,F8.2,T87,E9.4,T98,F7.5,T107,F8.2)
126     FORMAT(1H0,T40,'STANDARD ERROR OF ESTIMATE AND CORRELATION COEFFIC
       1IENT',//,T20,'STANDARD ENGLISH UNITS',T64,'S-I METRIC UNITS',T99,'
       2CORR. COEFF.',/, T15,'ELAST SEE',T27,'R-O SEE',T39,'S-H SEE',T56,'
       3ELAST SEE',T68,'R-O SEE',T80,'S-H SEE',T94,'ELASTIC',T104,'R-O',T1
       412,'S-H',/,T18,'KSI',T29,'KSI',T41,'KSI',T59,'MPA',T70,'MPA',T82,'
       5MPA',T97,'R',T105,'R',T113,'R',/)
127     FORMAT(T15,F7.3,T27,F7.3,T39,F7.3,T57,F7.2,T68,F7.2,T80,F7.2,T94,F
       16.4,T102,F6.4,T110,F6.4)
128     FORMAT(1H1,T27,'COMPARISON OF COMPUTED STRESS VALUES WITH EXPERIME
       1NTALLY OBSERVED VALUES',/,T36,'FOR SPECIMEN NO. ',A6,8X,'DATE OF T
       2EST ',2A6,//,
       3T47,'STANDARD ENGLISH UNITS',T85,'S-I METRIC UNITS',/,T24,'OBSERVE
       4D',T34,'ADJUSTED',T44,'OBSERVED',T54,'COMPUTED',T65,'STRESS',T78,'
       5OBSERVED',T88,'COMPUTED',T98,'STRESS',/,T25,'STRAIN',T35,'STRAIN',
       6T45,'STRESS',T55,'STRESS',T64,'DEVIATION',T79,'STRESS',T89,'STRESS
       7',T98,'DEVIATION',/,T26,'IN/IN  OR M/M',T47,'KSI',T57,'KSI',T67,'K
       8SI',T81,'MPA',T91,'MPA',T101,'MPA',/)
129     FORMAT(T24,F8.6,T34,F8.6,T44,F7.2,T54,F7.2,T64,F7.3,T78,F8.2,T88,F
       18.2,T98,F7.2)
130     FORMAT(1H0,T24,'***** NO ENTRIES FOR THE EXTRAPOLATED DATA POINT A
       1RE INCLUDED IN THE TABLE *****')
131     FORMAT(1H0,T24,'***** NO ENTRIES FOR DATA BEYOND S1 ARE INCLUDED I
       1N THE TABLE *****')
132     FORMAT(1H0,T24,'***** NO ENTRIES FOR DATA BEYOND THE INPUT VALUE O
       1F SPL ARE INCLUDED IN THE TABLE *****')
        END
@FOR,IS ORDER
        SUBROUTINE ORDER(N,S,E,EE,MORDER)
        DIMENSION S(1),E(1),EE(1)
        COUNT=0
        M=N-1
1       NOUT=0
        DO 4 I=1,M
        IF(S(I)-S(I+1))4,2,3
2       IF(E(I).LE.E(I+1)) GO TO 4
```

```
3       NOUT=NOUT+1
        SA=S(I)
        EA=E(I)
        SB=S(I+1)
        EB=E(I+1)
        S(I)=SB
        E(I)=EB
        S(I+1)=SA
        E(I+1)=EA
4       CONTINUE
        COUNT=COUNT+1
        IF(COUNT.LT.N) GO TO 5
        MORDER=1
        RETURN
5       IF(NOUT.GT.0) GO TO 1
        DO 6 I=1,N
6       EE(I)=E(I)
        RETURN
        END
@FOR,IS LSTSQ
        SUBROUTINE LSTSQ(X,Y,SL,OF,LI,LJ)
        DIMENSION X(1),Y(1)
        ET=0
        ST=0
        EET=0
        EST=0
        DO 1 I=LI,LJ
        ET=ET+X(I)
        ST=ST+Y(I)
        EET=EET+X(I)**2
1       EST=EST+X(I)*Y(I)
        C=LJ-LI+1
        DEN=C*EET-ET**2
        ENUM=C*EST-ET*ST
        ONUM=ST*EET-ET*EST
        SL=ENUM/DEN
        OF=ONUM/DEN
        RETURN
        END
@FOR,IS RJA75
        SUBROUTINE RJA75(Z,XM,BB)
        FUNC(Z)=Z+(3./7.)*Z**(XM)-BB
        KK=0
        RM=.00001
        L=0
        DZ=Z/100.
1       RZ=FUNC(Z)
        IF(ABS(RZ).LE.RM)GO TO 7
        KK=KK+1
        IF(KK.GT.100)GO TO 7
        IF(RZ.LT.0.)GO TO 3
2       L=L+1
        Z=Z-L*DZ
        GO TO 1
```

```
3       V=Z+DZ
        RV=FUNC(V)
        IF(ABS(RV).LE.RM)GO TO 6
        KK=KK+1
        IF(KK-100)4,4,7
4       IF(RV.LT.0.)GO TO 5
        DZ=DZ/10.
        GO TO 3
5       Z=Z+DZ
        GO TO 3
6       Z=V
7       RETURN
        END
@FOR,IS ISOTAN
        SUBROUTINE ISOTAN(W,XMT,XNT,CW,KW)
        FUNC(W)=W**XNT+(3.*(XMT+1.)/7)*W**(XNT+XMT)-CW
        L=0
        KW=0
        XCW=ALOG10(3.*(XMT+1.)/7.)
        RM=W/(10.**3.)
        DW=W/100.
        Q=W
        RQ=FUNC(Q)
        IF(ABS(RQ).LE.RM)GO TO 14
        IF(XNT+XMT)1,10,2
1       I=1
        GO TO 3
2       I=-1
3       IF(RQ.GT.0)GO TO 7
4       RW=FUNC(W)
        IF(ABS(RW).LE.RM)GO TO 14
        KW=KW+1
        IF(KW.GT.100)GO TO 14
        IF(RW.GT.0)GO TO 5
        L=L+1
        W=W-I*L*DW
        WV=W
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        GO TO 4
5       V=W+I*DW
        WV=V
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        RV=FUNC(V)
        IF(ABS(RV).LE.RM)GO TO 11
        KW=KW+1
        IF(KW.GT.100)GO TO 14
        IF(RV.GT.0)GO TO 6
        DW=DW/10.
        GO TO 5
6       W=W+I*DW
        WV=W
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        GO TO 5
C   ROUTINE WHERE FUNC(W) IS PLUS FOR W=1
```

```
7       RW=FUNC(W)
        IF(ABS(RW).LE.RM)GO TO 14
        IF(KW.GT.100)GO TO 14
        KW=KW+1
        IF(RW.LT.0)GO TO 8
        L=L+1
        W=W+I*L*DW
        WV=W
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        GO TO 7
8       V=W-I*DW
        WV=V
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        RV=FUNC(V)
        IF(ABS(RV).LE.RM)GO TO 11
        KW=KW+1
        IF(KW.GT.100)GO TO 14
        IF(RV.LT.0)GO TO 9
        DW=DW/10.
        GO TO 8
9       W=W-I*DW
        WV=W
        CALL SIZECK(XNT,XMT,XCW,WV,KX)
        IF(KX.GT.0)GO TO 12
        GO TO 8
C  ROUTINE FOR (XMT+XNT)=0
10      CHECK=CW-3.*(XMT+1.)/7.
        IF(CHECK.LE.0)GO TO 13
        W=CHECK**(1./XNT)
        GO TO 14
11      W=V
        GO TO 14
12      KW=200
        GO TO 14
13      KW=300
14      RETURN
        END
@FOR,IS SIZECK
        SUBROUTINE SIZECK(XNT,XMT,XCW,WV,KX)
        KX=0
        SIZES=XNT*ALOG10(WV)
        SIZEM=(XMT+XNT)*ALOG10(WV)
        SIZEL=XCW+SIZEM
        IF(ABS(SIZES).GT.20.)GO TO 1
        IF(ABS(SIZEM).GT.20.)GO TO 1
        IF(ABS(SIZEL).GT.20.)GO TO 1
        GO TO 2
1       KX=1
2       RETURN
        END
```

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